Step-by-Step Instructions on Obtaining, Compiling, and Running the LIS-WRF System

1. Coupling and Version Updates

a) LIS(v5.0)-WRF(v2.2): coupled 'in-house' and currently available and tested extensively on Discover, Columbia.

b) LIS(v6.0)-WRF(v3.0/3.1): coupling performed by WRF team (NCAR) as part of AFWA project. Tested on NCAR (Bluefire) machine but remains a work in progress on Discover.

c) Public Releases: WPS(v3.1) and vanilla WRF(v3.1) are available online and compile and run successfully on Discover. WPS(v3.1) can be used to generate WRF input and boundary condition for any current or previous versions of LIS-WRF as well (e.g. 2.2/5.0).

d) LSMs in LIS: Currently, the LSMs coupled to WRF and tested are Noah, CLM2, and TESSEL, but a generic coupling infrastructure is in place (and inherent in LISv6.0) to easily allow and implement other LSM couplings.

*Note: LIS-WRF as developed at GSFC and at NCAR (AFWA project) does not have a 'public release' as does LIS(v5.0 currently). However, we have been and are open to sharing the code for both formal and informal collaborations such as Jon Case at MSFC and summer interns.

*Note: LIS-WRF will be a major component of the MAP08 project towards creating a GSFC Unified WRF to incorporate the various radiation, microphysics, assimilation, and land surface/coupling advancements made with WRF at GSFC.

2. Installations and Build

a) Create a directory and download LIS-WRF from the Subversion repository
   a. mkdir LIS-WRF
   b. cd LIS-WRF
   c. Obtain the WRF source code from the repository:

"svn checkout https://flood.gsfc.nasa.gov/svn/external/WRF/branches/test-2.2 WRF2.2"

   d. cd WRF2.2 (this is your main WRF-level directory)
   e. Obtain the LIS source code from the repository:
      "**svn checkout https://flood.gsfc.nasa.gov/svn/5/public lis"**
   f. cd lis (this is your main LIS-level directory)

b) LIS-level setup
   a. copy the appropriate '**configure.lis**' file from /arch to /make
      i. make any necessary path (including ESMF) and compiler specifications for your platform
   b. edit the '**misc.h**' file to specify the coupled mode options as follows:
      #undef USE_NETCDF

#undef USE_HDF
#undef OFFLINE
#define COUPLED
#define INC_WATER_PTS

c. cd /MAKDEP and '**gmake**'
d. **compile the 3 libraries** (as done for offline LIS - see User's Guide for more info)
    i. cd lis/lib/grib and 'gmake'
    ii. cd lis/lib/read_grib and 'gmake [appropriate platform: Discover = ifc]'
    iii. cd lis/lib/w3lib and 'gmake'
e. This is all that needs to be done in /lis. You do not need to manually compile LIS in /make as for the offline code because this will all be done at the WRF-level compile (next step).

c) WRF-level setup and compilation of LIS-WRF
    a. consult vanilla WRF documentation to ensure proper setup of your environment (e.g. NETCDF paths)
    b. cd /WRF and run **./configure**
    c. choose appropriate option # for your system
    d. a **'configure.wrf'** file will be created - check compiler options and paths (inc. ESMF) before proceeding.
    e. type **'perl compile wrf'** to begin LIS-WRF compilation
    f. If successful, 'real.exe' and **'wrf.exe'** will be created in /WRF/main

d) Notes
    a. If working on Discover, configure.lis and configure.wrf files are available for reference.
    b. The clean script has been slightly modified. The "clean" command removes the WRF object files but not the LIS code. The "clean –a" command removes the objects, libraries, and executables from all directories (including LIS). Errors in compilation or significant modifications to the LIS-WRF code often require a 'clean -a' before recompiling.

2. Running the Coupled LIS-WRF System

a) Requirements and setup of Run Directory
    a. create run dir that contains:
        i. wrf.exe
        ii. wrfinputd01 and wrfbdyd01 files (from WPS and real.exe pre-processing)
        iii. namelist.input (WRF control file) and lis.config (see attached)
        iv. LIS restart files from spinup (offline) run
        v. all required symbolic links, directories, and tables for running offline LIS
            1. e.g. /noah_parms/*; /UMD-1KM/*; /forcing_variables/*

b) 'namelist.input' specifications
    a. as for vanilla WRF (see WRF documentation) with the following exception:

i. the flag indicating LIS-WRF coupled mode is the assignment of '3' to the LSM as follows: **SF_SURFACE_PHYSICS = 3, 3, 3,**
*this will trigger the use of the lis/runmodes/coupled configuration and allow for the passing of variables between LIS and WRF (below)

c) 'lis.config' specifications
   a. as for offline LIS (see User's Guide) with the following exceptions:
      i. Running Mode = 3 (LIS-WRF coupled mode flag)
      ii. Number of forcing variables = 17
      iii. input/forcing_variables.txt contains 17 entries
      iv. model timestep is now controlled by WRF (namelist.input setting)
      v. Ensure the #processors is specified correctly
      vi. Domain Specification:
         1. run domain x-direction size = ['e_we' - 1]
         2. run domain y-direction size = ['e_sn' -1]
         3. run domain lat/lon coordinates: acquire lower left and standard lat/lon from WPS intermediate metgrid (netCDF) file
      vii. Ensure LSM options and restart files are specified correctly

d) Running the model
   a. Submit job from the run directory (example script for 256 processor run on Discover is below)
   b. Diagnostics include:
      i. rsl.out.##: general WRF info
      ii. rsl.error.##: WRF info and errors
      iii. lisdiag.##: LIS info and errors
      iv. wrfout_d01_date_time: WRF output files
      v. /OUTPUT/E###/LSM: LIS output files

```
#PBS -S /bin/bash
#PBS -N liswrf_test
#PBS -l select=64:ncpus=4
#PBS -l walltime=11:59:00
#PBS -W group_list=r0620
#PBS -m a
#PBS -o bsout
#PBS -e bserr

cd /discover/nobackup/sntnello/LIS-WRF_run/liswrf2_2.2
ulimit -s unlimited

rm -rf lisdiag*
rm -rf rsl.*
rm -rf bs*

. /usr/share/modules/init/bash
```

module purge
module load comp/intel-10.1.017
module load mpi/impi-3.2.011

mpirun -np 256 ./wrf.exe

3. Post-processing of LIS-WRF output

a) LIS Output
   a. Land temperature and moisture fluxes, states, and sfc conditions (e.g. veg, albedo)
   b. Binary format: Easily plotted in GrADS using control (.ctl) file
   c. See 'LSMstats.d01' in /OUTPUT directory for list of variables being output

b) WRF Output
   a. Atmospheric flux, state, and diagnostic variables as specified in the Registry
   b. Land surface fluxes and 2m variables as passed from LIS-to-WRF
   c. netCDF format (use 'ncdump' to view contents)
   d. Many options for post-proc: simple program to convert from netCDF to GrADS binary format w/control file ('wrf2grads.exe').

WRF-LIS coupling : Interface variable specification

- **LIS(v5)-WRF(v2.2)**

Passing of variables occurs in:
WRF-side: /WRF/phys/module_surface_driver.F
LIS-side: /lis/runmodes/wrf_cpl_mode/*.F

- **LIS(v6)-WRF(v3)**

Passing of variables is handled more formally by WRF and fully ESMF-compliant:
Registry entries added
main/module_wrflis_coupler.F

WRF to LIS Interface

	WRF			LIS		
Variable	Name	Unit	+ Sign	Name	Unit	+Sign
Total Surface Incident Shortwave Radiation	swdown	W/m2	downward	SWdown	W/m2	downward
Incident Direct Shortwave Radiation	_tbd_	W/m2	downward	_tbd_	W/m2	downward
Incident Diffuse Shortwave Radiation	_tbd_	W/m2	downward	_tbd_	W/m2	downward
Surface Incident Longwave Radiation	glw*emiss	W/m2	downward	LWdown	W/m2	downward
Near surface Specific Humidity	qv_curr	kg/kg		Qair	kg/kg	
Near surface Air temperature	t_phy	K		Tair	K	
Height of lowest model level	dz8w	m		Zval	m	
Rainfall Rate	rainbl			Rainf	kg/m2s	
Snowfall Rate	_tbd_			Snowf		
Near Surface Northward wind	v_phy	m/s	northward	Vwind	m/s	northward
Near Surface Eastward wind	u_phy	m/s	eastward	Uwind	m/s	eastward
Surface Pressure	p8w	Pa		Psurf	Pa	
Surface Exchange Coefficient for Heat	chs	m/s		ch	m/s	
2m Surface Exchange Coefficient for Heat	chs	m/s		chs2	m/s	
2m Surface Exchange Coefficient for Moisture	chs	m/s		cqs2	m/s	
Near-surface Saturated Mixing Ratio	qgh	kg/kg		q2sat	kg/kg	
Cosine of Zenith angle	cosz	-		cosz	-	
Surface Emissivity	emiss	-		emiss	-	

LIS to WRF Interface

	LIS			WRF		
Variable	Name	Unit	+ Sign	Name	Unit	+ Sign
Latent Heat Flux	qle	W/m2	upward	lh	W/m2	upward
Sensible Heat Flux	qh	W/m2	upward	hfx	W/m2	upward
Ground Heat Flux	qg	W/m2	upward	grdflx	W/m2	upward
Surface Skin Temperature	avgsurft	K		tsk	K	
Surface Albedo	albedo	-		albedo	-	
Surface Emissivity	_tbd_	-		_tbd_	-	
Surface Roughness	znt	m		znt	m	
Surface Exchange coefficient for heat	acond_h	m/s		chs	m/s	
2m Surface Exchange Coefficient for heat	acond_h_2m	m/s		chs2	m/s	
2m Surface Exchange Coefficient for moisture	acond_q_2m	m/s		cqs2	m/s	

Notes:

1. **Surface exchange coefficients and wind components:** - To make this as generic as possible, we allow for passing of the full set of exchange coefficients (even if not used, as is the case for CLM), and the wind components (wind speed; even if not used, as is the case for Noah).
2. **Surface emissivity:** - We now use the WRF emiss*lwdown before passing the longwave. Noah also uses the WRF-passed emiss, but CLM and TESSEL use their own sfc emissivity values. We therefore allow the LSMs to use their emiss values, and therefore also pass/assign the emiss from the LSM to WRF. This is consistent with the literature which suggests passing emiss from the LSM to WRF (Polcher et al. 1998).
3. **Surface Albedo:** - We allow the LSMs to calculate their own albedo using cosz if necessary, and otherwise use the LIS albedo (as for Noah).